

Evolution of Theoretical Perspectives in My Research

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Abstract. Over the past 10 years I have been using socio-cultural theoretical perspectives to understand how people learn physics in a highly interactive, inquiry-based physics course such as Physics and Everyday Thinking [1]. As a result of using various perspectives (e.g. Distributed Cognition and Vygotsky's Theory of Concept Formation), my understanding of how these perspectives can be useful for investigating students' learning processes has changed. In this paper, I illustrate changes in my thinking about the role of socio-cultural perspectives in understanding physics learning and describe elements of my thinking that have remained fairly stable. Finally, I will discuss pitfalls in the use of certain perspectives and discuss areas that need attention in theoretical development for PER.

Keywords: Vygotsky, socio-cultural, distributed cognition, participation, concept formation, conceptual change, learning, learning process, cognitive, system.

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INTRODUCTION

This paper reports on four studies involving two similar physics curricula. The first and second study focused on the electrostatic unit of the Constructing Physics Understanding curriculum materials [2][3] and the third and fourth study focused on the force and motion unit and the magnetism unit of the Physics and Everyday Thinking curriculum [1]. In each of these studies the following research question was asked, How do non-science majors develop an understanding of both physics content and scientific practices (such as model-based reasoning)? The focus of this research was on the *learning process* rather than in whether or not students had learned. It was more a question of, "what does the learning process look like?"

The Physics and Everyday Thinking (PET) curriculum is built from the CPU curriculum and is a highly interactive, inquiry-based physics course designed to meet the needs of non-science majors, especially elementary teachers. PET course content focuses on the themes of interactions, energy, forces, and fields. Each unit consists of carefully sequenced sets of activities intended to help students produce (rather than consume) physics ideas through guided experimentation and questioning with extensive small group and whole class discussion. There is no textbook used for the course, students are expected to construct basic physics principles by working through the sequenced activities. Each activity has three parts, Initial Ideas, Collecting and Interpreting Evidence, and Summarizing Questions.

METHODOLOGY

Each curricular unit was videotaped, transcribed, time stamped, and coded. Each unit consisted of 5 to 7 hours of video-taped data including video of small group and whole class interactions. Another source of data was students written work such as their activity sheets and homework. The data were then coded using a generative coding scheme and later categorized into the following categories:

- Characteristics of discourse (e.g. content-specific discussions, metacognitive statements, and explicit statements about the nature of science and the nature of models in science).
- Conceptual commitments articulated and illustrated by the students (e.g. the curriculum asked for students' to describe their models of magnetic or electrostatic phenomena at various points throughout the unit).
- Use of scientific terminology
- Time spent sense making (including evidence-based reasoning, experience-based reasoning, mechanistic reasoning, analogical reasoning, and model-based reasoning).

FINDINGS

In each of the studies, three consistent observations were made.

1. Distinct changes in students' and groups' conceptual commitments were observed over the course of the unit.
2. Students struggled with terminology
3. There was a convergence on the target concept or model by all members of a small group of students by the end of each unit.

In order to create explanatory models for these observations and associated categorized codes, I utilized combinations of different theoretical perspectives. Each explanatory model shed light on the learning process, however each was incomplete and required either a re-analysis of the same data (as was the case in the electrostatics unit) or additional data, which was collected in the force & motion study and then the magnetism study. The theoretical framework associated with each successive explanatory model was a revision of its predecessor. While I will not discuss the particulars of any of these studies here, I report on the different theoretical perspectives that were employed to explain each of the findings. Finally, I discuss limitations and benefits of each perspective for understanding the learning process.

THEORETICAL PERSPECTIVES

The Genetic Psychology of Jean Piaget

Based on his work with snails and plants, Jean Piaget explained cognitive growth and maturation in terms of a combination of the theories of Darwin and Lemark [4]. He posited that balance between the structure of the organism and its environment was the goal of adaptation and that this was accomplished through the process he called "equilibration." Assuming that humans seek equilibration (balance between expectations and observations), when observations contradict the learner's expectations, the learner modifies her expectations through the process of assimilation and/or accommodation. Hence, learning is described as the process of modifying one's expectations to fit with the environment. This perspective allows us to investigate how the social and material environment leads to changes in conceptions of individuals.

Distributed Cognition of Edwin Hutchins

Based on his work in cognitive anthropology and drawing on the literature in linguistics, computer science, cognitive science, and Russian psychology, Edwin Hutchins developed the theoretical perspective of distributed cognition [5]. In this view, learning is

defined in terms of changes within a broader socio-cultural cognitive system consisting of individuals, individuals interacting with tools, and individuals interacting with each other and with tools. Both the cognition that is the task (e.g. building a model of magnetism) and the cognition that governs the elements of the task (reasoning with evidence and analogy, the process of consensus, representing ideas verbally and pictorially) take on part of the "cognitive load." Hence, cognition is distributed throughout elements of the system (including tools, individuals, and their interactions). Changes in any element of the system (such as an individual's understanding of a particular phenomenon) results in changes in the system. This perspective allows us to investigate not only how the social and material environment influences the learning of individuals, but also how iterations in a single individual's understanding fundamentally reshapes the social and material environment [2].

Vygotsky's Theory of Concept Formation

Based on his work with pre-schoolers, school children, and adolescents, as well as on his deep study of the work of Piaget and others, Lev Vygotsky established the theoretical perspective of concept formation which attempts to account for how cultural-historically developed artifacts and languages mediate the biological development of thought [6]. According to this perspective there exist two different types of concepts in the psyche of the individual: experience-based concepts (EBCs) and academic concepts (ACs) [7]. EBCs consist of everyday language and concrete experiences and are specific to individuals. ACs consist of formal language and sanctioned discourse practices that are specific to a community. ACs do not really exist in an individual, they are an estimate of the narrative that is officially (and otherwise) endorsed by a community. According to Vygotsky, learning occurs as EBCs are abstracted from the experiences to which they are tied and ACs are brought into coordination with the personal experiences of the learner. Each of these two processes mediates the other as EBCs and ACs grow towards one another to establish an individual's conceptual understanding at a point in time. Vygotsky holds that external development proceeds internal development, that is, a learner typically can imitate the discourse of a community before fully understanding it. In fact, it is exactly by engaging in the discourse that cognitive growth occurs. In addition to helping us understand what often look like misconceptions and cognitive growth of these naive conceptions, this perspective allows us to investigate how the individual appropriates the formal

symbolisms, language, and concepts that are taught in school.

Participation and Connectionist Networks

Based on their work in social anthropology and social learning theory, and deeply rooted in the work of Vygotsky, Jean Lave and Etienne Wenger proposed the notion of legitimate peripheral participation into a community of practice [8]. This perspective highlights the role of participation in the learning of individuals. As learners participate in a community, they change their behaviors through imitation and discourse practices of established members of the community. As they do so, they take on increasingly central roles to the community, ultimately participating as established members of the community themselves. This perspective allows us to investigate incomplete, fuzzy, or incorrect statements that students make as they learn the discourse of physics.

In their book, "A cognitive theory of cultural meaning," anthropologists Naomi Strauss and Claudia Quinn proposed the theoretical perspective of connectionist networks as a means for modeling and understanding how human beings appropriate cultural behaviors, understandings, and meanings [9]. While connectionist networks are probably too limited and homogenous to provide a complete mechanism for cognitive growth, I believe that this perspective is the best to which I have access at this time that at least provides a mechanism for how participation can lead to neurobiological cognitive development.

EVOLUTION OF PERSPECTIVES

Table 1 shows each finding and how it is explained using each theoretical perspective. Changes in my use of theoretical perspectives can be seen by following the explanation for each finding from left to right. As is shown in the table, students' conceptual commitments were initially explained in terms of mental models that mapped directly to the terminology that they used in small group and whole class discourse. Language was thought of only as a vehicle with which to communicate the conceptual content of their minds, it had no role in learning on its own. Over time, terminology and language became viewed as distinct from, but related to, the conceptual content of students' minds. Following the work of Vygotsky, learning became viewed as the process by which individuals imitate the narrative that characterizes a community. This includes the terminology and symbolism that they use and the practices that govern its use. "Misconceptions" are explained as an amalgamation of EBCs and ACs as the learner

attempts to imitate the endorsed narrative. Because it is not assumed that there is a direct mapping between what students articulate and what they think, what are thought of as misconceptions are often no more than a struggle with finding the right word, or on the other extreme, attempts to utilize the terms that are sanctioned by the teacher. As the learner attempts to imitate the endorsed narrative (mediated by her EBCs) she received positive reinforcement sometimes and negative other times. She repeats patterns that led to positive reinforcement and can often engage fully in the endorsed narrative without having a full conceptual understanding that underlies it. Again, following Vygotsky's reasoning, conceptual understanding that is internal to the individual comes long after the learner is able to externalize partial to full participation in the discourse community of interest (physics). Finally, while not fully satisfying, connectionist networks are used because they provide a mechanism by which this internalization of cultural meaning occurs. Interestingly, connectionist network models grew out of the behaviorist theoretical perspective on learning. It is for this reason that I sometimes refer to myself as a Vygotskian behaviorist.

LIMITS OF EACH PERSPECTIVE

Piaget's genetic psychology is useful for explaining how an individual's thinking is revised in the face of disconfirming evidence. It can also help to explain why students' in a group converge to a similar way of thinking (i.e. to an idea that "fits" with the environment). However, it provides less assistance in understanding how the social and material environment (including tools and their uses) are transformed throughout the process of learning. Vygotsky's theory of concept formation together with Lave and Wenger's notion of *participation* are useful for helping us understand how the social and material context get transformed as an individual attempts to appropriate the narrative that is endorsed by the community (including the language, symbols and practices involving their use). These perspectives help us move beyond what is happening in the heads of individuals (as impacted by the surroundings) and into thinking about how participation can fundamentally restructure both the social and material environment, which, in turn, lead to the restructuring of individuals' thinking. As is the case with distributed cognition (discussed below), it does not include a mechanism for how this participation actually restructures the cognition of the individual.

Distributed cognition provides ways of thinking about cognition as distributed throughout a socio-cultural, cognitive system. It is one of the few

perspectives that offers a way of thinking about how the social and material context gets transformed vis a vis the transformation of the individual learners (and vice versa). However it doesn't have a mechanism for accounting for why the individual leaves with more knowledge (although Hutchins uses a connectionist network-type computer model to demonstrate how this might occur [5]).

Connectionist networks can be helpful because they can begin to provide a mechanism for modeling how positive reinforcement of behavior (participation

in a community of practice) can lead to neurobiological growth. However, the theory may be too homogeneous and too limited because it provides no mechanism for how decisions are made about how or whether to participate. Furthermore, there is cannot account for how people make decisions about what information to attend to and how they go about attending to that information. Nonetheless, it provides a starting point for connecting the socio-cultural perspectives to perspectives on neurobiological growth.

TABLE 1. Evolution of theoretical perspectives in my research (time goes from left to right).

| Finding | Piaget Genetic psychology | Hutchins Dist. Cognition | Vygotsky Concept formation | Strauss & Quinn Connectionism |
|-----------------------------------|--|---|---|--|
| Changes in conceptual commitments | Conceptual commitments are described as "mental models." The focus is on transitions between mental models and those external things that influenced these transitions. While intermediate models are not seen as "misconceptions" they are viewed as concepts which will transition toward the canonical concept. | Focus on changes within the system—both in students' minds and in the physical setting (role of tools and students' scientific behaviors associated with the changing roles of tools) and how these changes influence one another. | Conceptual commitments are explained as the mediation of Academic Concepts (ACs) by Experience-Based Concepts (EBCs) and vice versa. Students coordinate ACs with experiences while they abstract EBCs away from the concrete experiences to which they are tied and toward the endorsed narrative of the community (ACs). At a given point in time in the learning process, a student's conceptual commitment is probably not fully aligned with the endorsed narrative of the community. | |
| Struggles with terminology | Struggles with terminology are mapped directly to conceptual difficulties. There is no clear distinction between language and concept. | Struggles with terminology was viewed as having to do with accessing a shared representation to mediate discourse toward a shared understanding. | Struggles with terminology have to do with students trying out ways of ways of talking in attempts of matching the endorsed narrative. They check for the response of others and positive or neutral feedback leads to continued use of those language practices. Conceptual understanding means using language and symbols in the same way as they are used by experts within the community. By doing this, internal conceptual development follows. As a result of initial "imitation," of the endorsed narrative the goal of the activity starts to change. This change of goal represents changes in identity (learning). | Learners reuse discourse practices that have not been negatively reinforced by community members. The more they use these discourse practices, the more likely that they will use them again (pathways get strengthened within a given context that provides positive feedback). |
| Convergence to target idea | Convergence is explained as the transitions of each individual's mental model to models to models with increasing explanatory power. Transitions are influenced by the social and material environment. Students' models converge because each successive model is a better "fit" with the external context. | Convergence is explained as development of an intersubjectively shared model among students in the group which is mediated by available tools such as computer simulator and activity documents. This is only possible because of the changing roles of tools that result from iterations of individual's understandings of the phenomenon. | Convergence is explained as development of an intersubjectively shared narrative among students in the group which is mediated by available tools such as computer simulator and activity documents. This is only possible because of the changing roles of tools that result from iterations of individual's understandings of the phenomenon. | Convergence is explained as development an intersubjectively shared narrative within the group and sanctioned by the broader classroom community including teacher. |

REFERENCES

1. F. Goldberg, S. Robinson, V. Otero, *Physics and Everyday Thinking It's About Time*, Armonk, NY, 2007.
2. V. Otero, "Conceptual Development and Context: How do they relate?" in *proceedings of the Physics Education Research Conference-2001*, edited by K. Cummings, S. Franklin, and J. Marx, AIP, Melville NY, 2002.
2. V. Otero, "Cognitive processes and the learning of physics, Part I and II" in *Proceedings of the International School of Physics "Enrico Fermi"-2004*, edited by E. F. Redish & M. Vicentini Amsterdam: IOS Press.
4. C. Fosnot, "Constructivism" in *Constructivism: Theory, perspectives, and practice* edited by C.T. Fosnot, 1998. New York: Teachers College Press, pp. 8-33.
5. E. Hutchins *Cognition in the Wild*, Cambridge MA: MIT press, 2005.
6. LS Vygotsky, *Thought and Language*, Cambridge, MA: MIT Press, and New York: John Wiley and Sons, Inc., 1962.
7. V. Otero and M. Nathan, *J. of Research in Science Teaching*, **45**, 497-523 (2008).
8. J. Lave and E. Wenger, *Communities of Practice: Learning, Meaning, and Identity*, Cambridge University Press, 1998.
9. C. Strauss and N. Quinn, *A Cognitive Theory of Cultural Meaning*, U.K., Cambridge University Press, 1998.